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STUDIES OF AN ACID SOIL IN ASSAM

BY

A. A. MEGGITT, B.Sc., F.C.S

Agricultural Chemist, Assam

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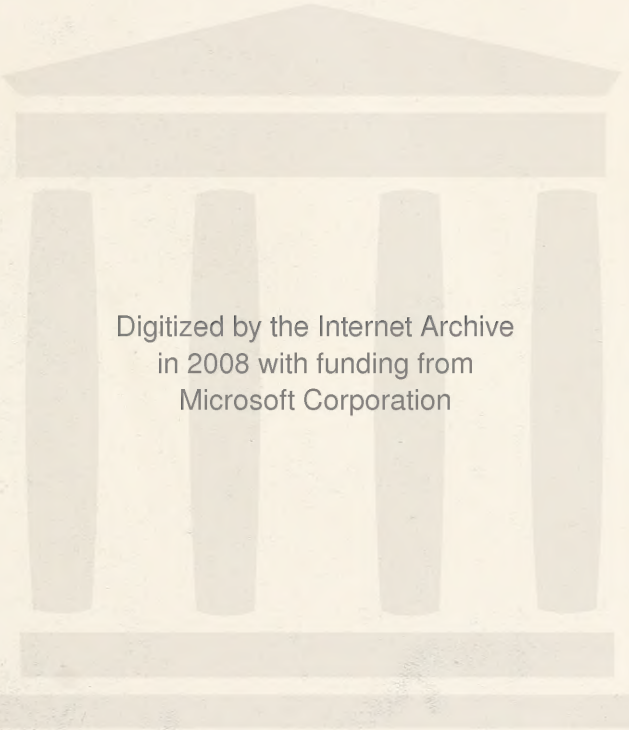
PREFACE.

Mr. A. G. Birt, Deputy Director of Agriculture, Assam, has been throughout jointly responsible for all the field work described or alluded to in this paper.

He modestly refuses to allow his name to appear as co-author, and I take this opportunity of expressing my thanks to him for assistance and advice always freely given; without it the work would have been impossible.

JORHAT, ASSAM,
March 1*st*, 1914.

A. A. MEGGITT.



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JORHAT FARM. BLOCK G.

The plots on the left were limed, those on the right unlimed; treatment is otherwise identical. Oats and Gram were sown across both areas. Observe the standing crops of both on the limed side, and the absolute failure on the other.

STUDIES OF AN ACID SOIL IN ASSAM

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INTRODUCTORY.

THE following pages contain some account of field and other work done on the old alluvium at the Government Farm, Jorhat, undertaken primarily with a view to ascertain, if possible, to what particular function of lime its observed early remarkably beneficial action on cropping there may be due.

Work on the liming problem has been going on since 1908 on this Farm.

It originated in the repeated failure of certain crops to survive the seedling stage during the *rabi* season even though well manured before sowing, and with no lack of soil moisture; the case was further aggravated in one instance by the fact that a green manure crop had been grown and ploughed in the previous rains, by way of preparation.

A full account of our early observations and work undertaken, will be found in the *Annual Report of the Jorhat Agricultural Experiment Station* for the year ending June 30th, 1912, pages 18-32. This is continued in the report of the same station for the year 1912-1913, pages 15-24. In these reports it is shown how after the application of lime several crops now grow much more luxuriantly, while others, *e.g.*, oats, gram, barley, mustard, linseed, *jowar* (*Andropogon Sorghum*), etc., which failed heretofore to outlive the seedling stage, now mature their crops normally.

An account of the further experiments laid down to study other aspects of manuring in relation to the liming problem is given in the same reports. Data in regard to the chemical and mechanical composition of the soil will be found in the Appendix.

Previous to being taken over by the Agricultural Department the land had been out of cultivation for many years ; it was covered by short scrub jungle and very coarse grass, and was used solely for grazing purposes.

The soil is very old alluvium and is a light loam lying over a compact reddish yellow sandy subsoil.

The surface soil is shallow, from 3 to 6 inches deep, fairly retentive of moisture and in good physical condition.

The subsoil is redder, and very deficient in organic matter, which combined with the fact that it has not been disturbed for very many years makes its physical condition temporarily poor.

The soil drains fairly readily.

The surface and subsoils are fairly sharply divided in the field, but are essentially the same in chemical and mechanical composition, the surface soil having become darker in colour and ameliorated by cultivation and incorporation with organic matter. The mechanical analysis shows that both soils are essentially very similar, about 80% of either falling in the fine sand and silt grades, only relatively small quantities of the clay fraction being present.

The soil is acid in reaction and very deficient in carbonate of lime.

Phosphoric acid is low both as to total and available supplies. There is thus a real as opposed to a mere temporary lack in respect of this element of plant-food.

This lack of phosphoric acid is probably aggravated by the absence of sufficiently large amounts of carbonate of lime and humus, high percentages of which may, and often do, offset a smaller percentage of phosphoric acid.

Of potash there is no dearth, and there would appear to be no immediate need for special potash manuring.

The amount of organic matter in the surface soil is possibly greater than obtains in many Indian soils, but there can be no doubt that a light soil of this character will be much improved by an increase in humus content. A good deal of the organic matter present consists probably of old residue of little value. Green manuring with cowpea has improved the soil enormously of recent years. The percentage of nitrogen present in the surface soil is what would normally be considered a fair one, but in view of the absence in anything like adequate quantity of carbonate of lime, conditions for nitrification are not as favourable as they might be, and an increase in the amount of nitrogen is indicated as desirable.

As to maximum saturation capacity this soil agrees well with figures quoted for similar soils in Europe: the figures suggest that the optimum proportion of water for the growth of the plant is some 13-16%.

The values for minimum saturation capacity are lower than those cited (Hall, *The Soil*, page 69) for similar soils in England, and this is probably due to the lower humus content of our soils. The hygroscopic capacity is low, and suggests the power of the soil to give up its moisture freely to crops in dry periods.

As previously explained the outstanding feature of our early experiments was the extraordinary effect of lime. Without it many crops could not be induced to survive even the seedling stage; after liming they were easily matured. (See Frontispiece.)

The question naturally arose as to why lime acts in this marked way. The reasons might be found in a number of possible causes of a physical, purely chemical, bio-chemical, biological and physiological nature; some of these aspects merge into one another and are very closely related, and are moreover imperfectly understood at present, so that it were futile to attempt any fine discrimination.

The soil is distinctly not of the type one usually associates with adverse physical conditions, or one upon which one would expect lime to confer much physical benefit perhaps. A good tilth and seed bed is easily obtained, the soil is naturally fairly retentive of moisture, the rainfall is high (80-90 inches) and well distributed, some rain falling nearly every month of the year. Knowing the soil one would not readily ascribe any considerable part of the action of lime to physical changes (*a*).

One of the very earliest actions of lime is a purely chemical one, which it exercises merely by virtue of its power to neutralise acids. So much lime is required by this soil to satisfy its various requirements that a dressing of 2 tons slaked lime per acre causes but a very slight and temporary increase in the percentage of calcium carbonate in the surface soil, as is clearly shown by the following figures :—

		3 months after liming.		18 months after liming.	
		% $CaCO_3$	Reaction	% $CaCO_3$	Reaction.
0 Lime plot	0 — 3″	0·02	Acid	0·02	Acid
	3 — 6″	0·015	,,	0·015	,,
30 maunds Lime plot (1 ton)	0 — 3″	0·04	Fairly alkaline	0·02	,,
	3 — 6″	0·02	Acid	0·02	,,
60 maunds Lime plot (2 tons)	0 — 3″	0·11	Strongly alkaline	0·02	Slightly alkaline.
	3 — 6″	0·015	Acid	0·015	Neutral.

These results shed some light on the question as to the quantity of lime which will be required to establish even a small working reserve of carbonate of lime in the surface soil.

(*a*) On stiffer soils the physical changes would, no doubt, be of much greater moment. Thus work on the old alluvium at Dacca has shown that while the use of lime there reduces the amount of the clay fraction (< 0·002 m.m. diam.), presumably by flocculation into larger aggregates from about 17 to 13% in a water sedimentation, at Jorhat so far this is not so, the limed and unlimed surface soils returning identical figures. There is, however, experimental evidence that deeper down in the Jorhat soil, some flocculation does take place as a result of applying lime to the surface.

A good deal of the added lime combines with acid organic compounds present, neutralising and fixing them, as is shown by the fact that whereas the unlimed soil gives up its humus to dilute ammonia quite readily yielding a dark brown solution, after liming it only does so after a preliminary weak acid digestion to break up the lime compounds formed.

Schloesing[1] has ascribed valuable physical properties to these so called calcium humates in certain soils. Working with silicious sand he found that "1% humic acid in the form of calcium humate had as great a cementing power as 11% of plastic clay."

Soils contain other colloid bodies than clay; amongst these are humus, hydrated ferric and aluminic oxides, hydrated silicic acid, and hydrated acid silicates, the latter accounting no doubt partly for the acidity of soils which are strongly acid and withall deficient in humus.

Possible interaction of lime with some of these colloidal substances, *e.g.*, a reaction with hydrous acid silicates, coupled perhaps with dehydration where quicklime is used—whereby may result non-colloidal anhydrous silicates—might conceivably modify the properties of the soil (*a*). Hence it is possible that lime may affect this soil physically and thereby alter its power to supply moisture to the plant. However from the fact that in the absence of lime some crops, *e.g.*, *matikalai* (*Phaseolus mungo*) do grow even in the *rabi* season and make some sort of a crop, while most others, *e.g.*, oats, gram, etc., sown at the same time die as seedlings (though examination has always disclosed the presence of sufficient soil moisture in the latter case), also the fact that seeds germinate apparently as well before as after liming, and again *jowar* sown in

[1] Warington. *Physical Properties of Soil*, p. 27.

(*a*) Indications are not wanting that heavy liming may have an influence on the stiffness of straw of cereals, which is possibly connected with changes in the silica compounds of the soil. Analytical data to hand point to variations in silica content of the straw from limed and unlimed areas, but in the absence of information as to the probable extent of the variation in silica content of a given sample of straw from one and the same plot, and until further analytical data are to hand, it were futile to attempt to draw any conclusions. This part of the problem will probably require very special methods of investigation.

the rains always succumbs in the absence of lime. it seems to be reasonably clear that the failure of certain crops to survive is not due to any lack of soil moisture, and further the marked action of lime is not to be sought in modified water relationships as between soil and crop.

Added lime might function as a direct source of plant-food in respect of the element calcium, or by liberating other foods from the soil's reserves. It is very difficult to believe that the soil does not contain sufficient lime compounds to serve fully the requirements of crops for this element. Few soils do not. Were any large part of its effect due to its acting as a direct source of plant-food, then a dressing of 1 ton per acre would surely supply all that was necessary, and yet in the case of *jowar* a much bigger crop resulted from the application of 2 tons per acre.

O. Loew has attached great importance from a physiological standpoint to the presence in the soil of lime and magnesia in certain definite ratios for various crops. The results of our experiments do not at all connect the value of lime with any such relationship.

The beneficial action of lime may be found in its power of destroying by oxidation, or otherwise, directly or indirectly, noxious organic soil compounds: possibly preventing their formation, or at any rate their accumulation.

Some of these toxic substances are themselves acids, *e.g.*, the hydroxystearic acids isolated from certain infertile soils by Schreiner and his associates. Schreiner and Reed[1] have shown that "the maintenance of the most favourable soil conditions requires the oxidation of the organic soil constituents to a comparatively high state of oxidation."

They draw the further conclusion from their work, that though plant roots themselves are able to oxidise a certain amount of deleterious organic material, their power to do so may be entirely inhibited in the presence of excess of toxic material, but that lime salts increase the amount of oxidation possible in the latter case.

[1] *Bulletin 56, Bureau of Soils, U. S. Dept. of Agriculture.*

Again they conclude that "the process of oxidation by roots is largely, if not entirely, due to the activity of a peroxidase produced by the roots. This oxidising enzyme is most active in neutral or slightly alkaline solutions and may be inhibited by the presence of acid."

Laboratory examination of the Jorhat soil had already disclosed positively the presence of an acid organic compound, definitely toxic to *jowar* seedling plants in extremely dilute culture solution (30 parts per million), the toxicity of which was partly or wholly negatived by the addition of a complete nutrient solution containing nitric nitrogen, or by the addition of lime to neutrality. (Plate V.) The observations thus made in culture solution agree exactly with field results, and render it reasonably clear that the soil's infertility to certain cropping is due in no small part to the presence of toxic organic material. More recent work has proved that this body is not only non-toxic to transplanted paddy seedlings, but that it appears actually to favour their development in such concentrations as were definitely toxic to *jowar*. That this toxin is an actual constituent of the soil, and is not rather a compound formed during the process adopted for its isolation, is clearly proved by the fact that a water extract of the soil was itself quite toxic to *jowar* seedlings.

Further, examined by the method of Raciborski[1], using phenolphthalin as indicator, the author has been able to show that the presence of this toxic body in solution does actually lead to a diminution of the root oxidising power as measured by the rate of oxidation of phenolphthalin to phenolphthalein.

Considered from the biological point of view the presence of noxious organic material in the soil besides being toxic to the plant itself, must also be inimical to many forms of bacterial life.

The presence of acidity in any form is contrary to the best functioning of certain normal soil micro-organisms which depend for their proper action upon the presence of a sufficiency of basic

[1] *Bul. Acad. Sci. Cracovie, math.-nat.* Cl. 1905, 338.

ingredients. By its power then of neutralising acidity and its action on toxic soil material, whereby the soil becomes a suitable culture medium for a normal bacteriological flora, lime would stimulate bacterial activity leading to that marked improvement in the growth and colour of crops which has all along followed its use in our experience.

The chemical examination of the soil and the early field observations and cropping results led us to believe that the fault in the soil was due to a definite lack of basic constituents, to which the presence of toxic compounds, which may partly or wholly give rise to the acid condition, is attributable.

It seemed likely then on general grounds that the early beneficial action of added lime was primarily due to its supplying the base necessary for the neutralisation of the soil acids, some of them toxic, and to its power to bring about such other changes in the bio-chemical soil factor as results in the destruction of toxic organic compounds, whether by micro-organisms, enzymes or other vital agencies, and in checking their future formation, or in any case their accumulation to the danger point in the soil.

EXPERIMENTAL.

A field experiment comprising some 52 small sub-plots was, therefore, commenced in the hope of throwing more light on some of the points raised in the introduction, and in order to fine down the possible reasons for its early beneficial action. It was considered far more satisfactory to carry out the work on small field plots, rather than in pots; an experiment carried out in tubs has proved that for the purposes of this investigation, tests so conducted in no wise approximate to field conditions, and give wholly irregular results. The scheme provides for the testing of each individual treatment with and also without lime.

Various alkali plots were included, *e.g.*, sodium carbonate, magnesium carbonate and potassium carbonate, to compare with the plot receiving lime only, another getting finely ground limestone.

Other two plots were given calcium sulphate and chloride respectively, to test the direct plant-food theory.

The three nitrates of potassium, sodium and lime were each separately used with a view to seeing whether the supply of readily assimilable nitrogen alone has any effect on cropping, in the absence of first neutralising part or the whole of the soil acidity.

Two further plots received sulphate and muriate of potash respectively, supplying soluble potash in the same amount as provided for in one of the plots manured with carbonate of potash.

The experiment was also designed to show how the use of certain acid or physiologically acid manures in the absence of liming is limited by the small amount of carbonate of lime present in the soil. Sulphate of ammonia alone and in combination with other manures enters into the scheme, and again plots are included whereon acid and basic forms of phosphoric acid are applied.

Besides those plots which receive either potash or nitrogen or phosphoric acid only, there will be found other plots manured with both potash (as sulphate) and also nitrogen, either as sodium nitrate or sulphate of ammonia ; others getting superphosphate in addition to the above combinations ; again, others receiving superphosphate in addition to one or other form of soluble nitrogen : and finally one plot with superphosphate and sulphate of potash in the absence of nitrogen in any form.

All the above combinations were applied with and without previous liming, and may serve to indicate the relative importance of one or other kind of plant-food in the economy of this soil.

The whole scheme will be readily grasped by referring to the plan of the experiment, Fig. I, and table of manuring, Table I.

The middle area A B C D was limed at the rate of 30 maunds per acre.* There are thus 26 plots, each of 1/100 acre, the inner half of each being limed.

A B and D C represent dividing lines of bricks between the limed and unlimed half of each plot.

---

* 30 Maunds = 1 ton approx.

Each plot was separated from those on either side of it by a 3 feet division.

Table I.

The manuring of the various plots was as follows :—

Plot.	Manure used.	Rate per acre.	Remarks.
1 & 1a.	Ground limestone	30 mds.	
2 & 2a.	Sodium carbonate. Monohydrate ..	1,000 lbs.	Equal to 10 mds. slaked lime in neutralising power.
3 & 3a.	Do. do.	500 ..	Equal to 5 mds. do.
4 & 4a.	No manure.		
5 & 5a.	Magnesium carbonate	1,000 ..	Equal to 15 mds. lime in neutralising power.
6 & 6a.	Potassium do. .. .	328 ..	
7 & 7a.	Potassium carbonate	164 ..	Containing potash equal to that supplied in 2 cwt. sulphate of potash on plots 18 & 18a.
8 & 8a.	Flour phosphate	600 ..	Equal in money value to the basic slag used on plots 9 & 9a.
9 & 9a.	Basic slag	400 ..	Supplying 80 lbs. P_2O_5 per acre.
10 & 10a.	Superphosphate. Concentrated .	200 ,,	Supplying 80 lbs. sol. P_2O_5 per acre.
11 & 11a.	Sulphate of ammonia	250 ..	Supplying 50 lbs. nitrogen per acre.
12 & 12a.	Sulphate of lime ..	1000 ..	Containing approx. same amount of lime as 30 mds. slaked lime.
13 & 13a.	Calcium chloride .. .	1000 ,,	Adding same amount of calcium as exists in 10 mds. lime approx.
14 & 14a.	Sodium nitrate .	322 ,,	Supplying 50lbs. nitrogen per acre.
15 & 15a.	Potassium nitrate .. .	384 ,,	Do. do.
16 & 16a.	Calcium	384 ..	Do. do.
17 & 17a.	Muriate of potash	224 ..	
18 & 18a.	Sulphate of	224 ..	Supplying same amount of potash as supplied by carbonate of potash in plots 7 & 7a.
19 & 19a.	No manure.		
20 & 20a.	Sodium nitrate . ..	322 ,,	
	Superphosphate ..	200 ,,	
	Sulphate of potash . .	100 ,,	
21 & 21a.	Sulphate of ammonia .. .	250 ..	Superphosphate supplied
	Superphosphate .	200 ..	80 lbs. phosphoric acid
	Sulphate of potash .	100 ..	per acre.
22 & 22a.	Sodium nitrate	322 ..	Sulphate of potash 50
	Superphosphate	200 ..	lbs. potash per acre.
23 & 23a.	Sulphate of ammonia .	250 ..	Nitrate of soda 50 lbs
	Superphosphate	200 ,,	nitrogen per acre.
24 & 24a.	Sodium nitrate .	322 ,,	Sulphate of ammonia
	Sulphate of potash .	100 ,,	50 lbs. nitrogen per
25 & 25a.	Sulphate of ammonia	250 ..	acre.
	Sulphate of potash .. .	100 ..	
26 & 26a.	Sulphate of potash	100 ,,	
	Superphosphate	200 ..	

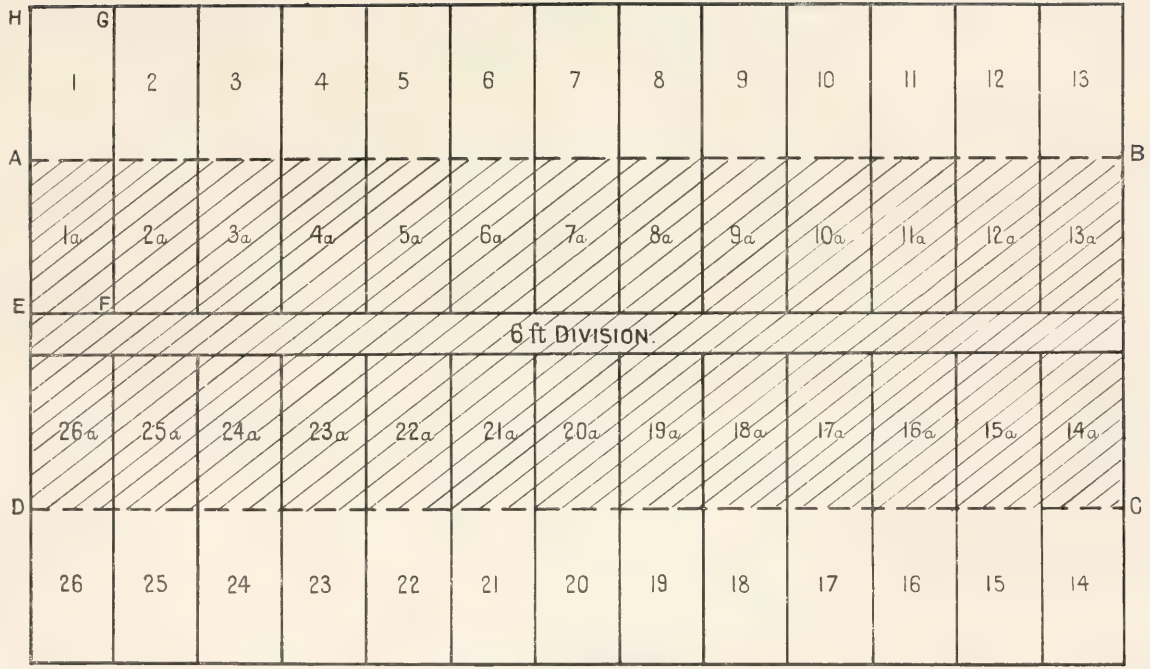

FIG. 1. PLAN OF EXPERIMENT.

Inner sub-plots 1*a* to 26*a* were limed at the rate of 30 mds. per acre. (Shaded area.)
Outer sub-plots 1 to 26 were unlimed.
Area E F G H = $\frac{1}{4}$ acre.

(a)

GENERAL VIEW OF PLOTS DESCRIBED IN THIS MEMOIR.

(b)

SHOWING THE ACTION OF PHOSPHATE ON WEED PRODUCTION.

It is to be emphasized that in addition to the manuring as shown in the table above, the inner or "a" sub-plots each had 30 maunds slaked lime per acre.

As regards the sodium carbonate plots, the amount added was arbitrary: in view of its solubility the amounts used were thought ample for the purposes of this test, although only equal in acid neutralising power to 10 and 5 maunds good slaked lime per acre, respectively.

Potassium carbonate could not be applied in such quantities as would be necessary to supply the equivalent in neutralising power of the sodium carbonate above, chiefly by reason of the very large amount of potash which such quantities would add to the soil. It was considered sufficient to use such quantities as would supply potash in amounts respectively equal to and double that supplied as sulphate of potash in sub-plots 18 & 18a.

The flour phosphate used in plots 8 & 8a, is a very finely ground raw mineral phosphate; 85% passes a 100 mesh sieve, and it contains 25% phosphoric acid as tri-calcic phosphate, and some 23% of carbonate of lime.

The basic slag contained 20% phosphoric acid and the concentrated superphosphate 40% soluble phosphoric acid. The other artificials were of the usual average composition.

Slaked lime was applied to the inner area at the rate of 30 maunds per acre in April.

The whole experimental area was subsequently green-manured with cowpea during the rains, the more luxuriant growth being over the limed part, though the crop elsewhere was a good one. Cowpea was turned in during August, and all the other manures were applied during the third week in October in fine weather, and on nice soil moisture.

In the case of those plots receiving soluble nitrate, as it was thought desirable to have nitrate present at an early stage in the life of the plant to see whether it would prevent the death of the seedlings, the plan was adopted of applying half the nitrate just

before sowing, and the second half some weeks later as a top dressing, rather than the alternative and usual method of applying it entirely as top dressing.

All manures were evenly spread, and the plots then immediately cultivated.

No rain fell between the application of manures and sowing, which was done towards the end of October on good seed bed.

Oats was decided upon as the test crop, because up to this time this crop had invariably totally succumbed in the seedling stage, even though well manured with cowdung following green-manuring, except where moderate lime dressings or heavy application of wood ashes had been used.

In addition then to providing a sharp qualitative separation of manures, or combinations thereof, into two classes, *viz.*, those which serve to carry the crop through to maturity, and those which do not, it seemed probable that this crop would also permit of a measure of quantitative comparison between manures of the former class.

Further, it was deemed justifiable to attempt to estimate the extent of the improvement, due to manuring, in general agricultural value of the soil of each plot by the crop of oats produced, since we have evidence that many other crops, *e.g.*, soy beans, cowpeas, *jowar*, gram, linseed, *matikalai*, mustard, barley, are all considerably benefited by liming, and many of them, like oats, had entirely refused to grow in its absence.

All these crops have shown that before we can expect a really good outturn from any one of them, some base such as lime must be added to the soil, presumably to reduce acidity, and it seemed to us probable that the extent to which any manuring or combination of manuring will, either immediately or more slowly with lapse of time, effect this end, would appear to be one of the chief factors in determining its value for most field and garden crops on similar soils.

OBSERVATIONS DURING GROWTH.

Germination was very uniformly good on all plots and was complete by November 2nd; subsequent to sowing rain fell on the following dates. November 1st, 2nd, 3rd and 24th. December 8th, 16th, 17th, 20th, 25th, 28th.

November 6th.—All plots were looking well and normal.

November 18th.—The limed plots were all growing normally. Sub-plots 20*a*, 21*a*, 22*a*, 23*a* and 26*a* being then the best, followed closely by 8*a*, 9*a*, 10*a*, while 13*a* was the poorest distinctly.

The unlimed plots were in many cases already turning yellow and dying off, the phosphate plots being at the time slightly better than the average, while the sulphate of ammonia and calcium chloride plots were manifestly worse.

December 18th.—The general effect was most striking. All the limed plots were carrying healthy looking crops, while on the unlimed plots the plants had already quite died out in many cases, *viz.*, on sub-plots 4, 11, 12, 13, 14, 15, 16, 17, 18, 19, 21, 23, 24, 25.

Of the remainder of the unlimed plots only those which had received additions of a basic character, *viz.*, plots 1, 2, 3, 5, 6, 7, 8, 9 were carrying anything worthy the name of a crop, but even in these cases they did not, with the possible exceptions of plots 1, 8, 9, at all compare with the crop on the limed ends.

On sub-plots Nos. 10, 20, 22 and 26 some of the seedlings had died off, but the stronger ones were still struggling.

It will be noticed that the latter four plots had all in common received phosphoric acid. Phosphoric acid had also been applied to sub-plots 21 and 23, but in these two cases in conjunction with sulphate of ammonia as the source of nitrogen.

The previous death of the crops then on these two plots can only be ascribed to the toxic effect of the sulphate of ammonia, in the absence of lime. It is to be noted that the limed ends of the

same plots, *viz.*, sub-plots 21*a*, 23*a* were quite as good at this time as sub-plots 20*a* and 22*a*, on which the source of nitrogen was nitrate of soda.

At this time the most clearly outstanding feature was the action of lime, followed by that of the other applications of a basic character.

Phosphoric acid even as superphosphate, in the absence of lime, was exercising a very slight positive effect apparently, but was far more potent where applied in a basic insoluble form.

Potash seemed to be without any effect at present, except where used as the alkaline carbonate.

Nitrate nitrogen alone in the absence of lime had no effect, but appeared to increase that of superphosphate when the two were used together.

Sulphate of ammonia had killed off its crop earlier than it had succumbed on the plots receiving no manure at all, and in addition appeared to absolutely negative the slight positive effect of phosphoric acid.

Sulphate of lime had apparently no effect whatever, while calcium chloride appeared to be definitely toxic.

On December 19th the remaining half of the various nitrate dressings was applied to sub-plots 14, 14*a*, 15, 15*a*, 16, 16*a*, 20, 20*a*, 22, 22*a*, 24 and 24*a*, the first dose having been given previous to sowing for reasons stated earlier.

February 24th.—By this time the limed sub-plots were ripening off. All the plots to which had been applied phosphoric acid in any form, in addition to lime, *viz.*, 8*a*, 9*a*, 10*a*, 20*a*, 21*a*, 22*a*, 23*a* and 26*a*, were fully ripe and were cut and stooked on this date. The other lime plots were about a fortnight later in ripening off.

Such of the unlimed sub-plots as had carried their crops through, were the latest to ripen, some of them not ripening until a month later than this date.

Plots 1 & 1a. Common manuring - Ground Limestone.

Plots 19 & 19a Common manuring - Nil

Plots 3 & 3a. Common manuring - Sodium Carbonate, light dressing.

Plots 5 & 5a. Common manuring - Magnesium Carbonate.

Speaking generally at this time the indications were qualitatively the same, but much more pronounced than on December 18th.

The effect of the top dressing of nitrate was *nil* on the non-limed halves of such plots as received it, except that in the cases of sub-plots 20 and 22, *i.e.*, where used with phosphoric acid, it produced a fair improvement in the crop. These plots are now forming some grain, though many plants are stunted and may not do so.

Phosphoric acid, even as superphosphate, would appear to have exercised a small but distinct ameliorating effect throughout the experiment, especially where reinforced by nitrate. This has been marked on the oats, but was particularly evident at this time in the growth of bottom weeds.

Thus, comparing the unlimed sub-plots, all those which had phosphoric acid were now carrying a thick bottom crop of weeds. This was not due to the thin crop of oats present, because other unlimed plots with no oats at all surviving were moderately free from weeds also. (See Plate I (*b*).)

Again, though the use of sulphate of ammonia along with phosphoric acid sufficed to kill the oats, it by no means affected the luxuriance of the weed growth.

Where used alone, however, sulphate of ammonia proved too toxic even for weeds, sub-plot 11 being absolutely bare of all vegetation whatsoever, indeed this sub-plot was undoubtedly by far the most toxic in the whole of the experimental area.

The crop from each plot was cut and stooked as it became ripe, and allowed to dry on the plot, being finally weighed.

No separation into grain and straw was attempted as in almost all cases some of the grain was eaten by rats during drying off.

Table II shows at a glance the manuring of each sub-plot and the weight of crop harvested.

Table II.

Final outturns of plots (grain and straw.)

Plot.	Manure used.	Unlimed sub-plot.	Limed sub-plot.
		lbs.	lbs.
1 & 1a.	Ground limestone	7½	16¾
2 & 2a.	Sodium carbonate. Heavy dressing . ..	4	24
3 & 3a.	Sodium carbonate. Light „	6½	22¾
4 & 4a.	*Nil.*	*Nil.*	16
5 & 5a.	Magnesium carbonate	6½	16¾
6 & 6a.	Potassium carbonate. Heavy dressing	7	19¼
7 & 7a.	Potassium carbonate. Light „ .. .	2½	20
8 & 8a.	Flour phosphate	7½	15¾
9 & 9a.	Basic slag	7	17
10 & 10a.	Superphosphate	¾	15
11 & 11a.	Sulphate of ammonia	*Nil.*	13½
12 & 12a.	Sulphate of lime	*Nil.*	13
13 & 13a.	Calcium chloride	*Nil.*	10
14 & 14a.	Sodium nitrate	*Nil.*	17¼
15 & 15a.	Potassium nitrate	*Nil.*	18
16 & 16a.	Calcium nitrate	*Nil.*	16½
17 & 17a.	Muriate of potash	*Nil.*	20¾
18 & 18a.	Sulphate of potash	*Nil.*	18
19 & 19a.	*Nil.*	*Nil.*	14½
20 & 20a.	Sodium nitrate Superphosphate Sulphate of potash	5¾	21¼
21 & 21a.	Sulphate of ammonia Superphosphate Sulphate of potash	*Nil.*	20
22 & 22a.	Sodium nitrate Superphosphate	4½	19½
23 & 23a.	Sulphate of ammonia Superphosphate	*Nil.*	18
24 & 24a.	Sodium nitrate Sulphate of potash	*Nil.*	19
25 & 25a.	Sulphate of ammonia Sulphate of potash	*Nil.*	17½
26 & 26a.	Sulphate of potash Superphosphate	2½	23

The results are striking, and taken in conjunction with our earlier experience and various observations made throughout the growing period, appear to warrant certain very definite deductions.

All the limed sub-plots produced crops, varying somewhat in magnitude, the smallest yields resulting from the use of calcium chloride or sulphate in addition. The biggest crop, strange to say, occurred in sub-plot 2*a* which had the heavy dressing of sodium

Plots 7 & 7a. Common manuring - Pot. Carbonate, light dressing

Plots 18 & 18a. Common manuring - Sulphate of Potash (supplying the same quantity of Potash as applied in basic form to Plots 7 & 7a).

Plots 26 & 26a. Common manuring - Superphosphate

carbonate as well as lime. In the absence of the latter, this large dose of sodium carbonate appeared throughout the experiment to be less beneficial than the smaller dressing, and the result confirms this. It had a marked de-flocculating effect on the surface soil. With lime, this result becomes reversed; the average superiority in the latter case, of these sodium carbonate plots over many of the other limed plots, may be due to precipitation of the lime as carbonate in a very fine state of division in the soil. It is not desirable to lay much stress on the comparatively small variations between the yields of the various limed sub-plots, as there will be seen to be a difference of some 10% in crop between the two otherwise unmanured plots 4*a* and 19*a*, and further, wet weather necessitated some of the crops standing in the field a considerable time before weighing, resulting in some loss by rats here and there.

The chief interest of the experiment lies elsewhere. *Thus, of all the unlimed sub-plots, the only ones to carry a crop to maturity at all were the whole of those to which basic manures had been added on the one hand, and on the other four plots in which superphosphate was the only constant manurial factor.*

On the face of it, it seems extremely improbable that the favourable action of lime, sodium carbonate, potassium carbonate and magnesium carbonate (*vide* Plates II and III) can be credited to any common attribute other than that of providing a base and thus diminishing the soil acidity, and probably rendering harmless toxic compounds which accompany it.

From the physical point of view, lime and the alkaline carbonates affect soils in very different ways, lime resulting in flocculation of the finest particles, while sodium and potassium carbonates have a de-flocculating action. De-flocculation was very marked on plot 2, which received the heavier dressing of sodium carbonate.

If therefore any large part of the favourable action of lime were due to its flocculating powers, one would not have expected

the alkaline carbonates to have the same qualitative effect on crop production that lime has.

Again, Schloesing found that sulphate of lime had a flocculating action, and yet this substance applied at the rate of 50 maunds per acre to sub-plot 12 failed to produce any crop at all.

There was no lack of soil moisture throughout the course of experiment, which makes it the more difficult to believe that altered water relationships as between soil and plant, which may follow the use of certain manures such as lime, can have played any but a very small part in the general result.

Again, if lime functioned in any considerable measure as a carrier of direct plant-food to the soil, why should the alkaline carbonates influence crop production as they do ?

Further, if the demands of the crop on the soil for additional lime as plant-food were great, one would have expected a ready response in crop production from the application of 50 maunds sulphate of lime on plot 12. As a matter of fact, the seedlings died out on this plot quite early.

Some of these alkalies might function by virtue of their power to liberate available plant-food from the soil's reserves, *e.g.*, assimilable potash might result.

Particularly might it be argued that potassium carbonate exerted a positive effect by supplying soluble potash.

Both these arguments lose their force in that soluble potash applied as sulphate, or as muriate, to plots 17 and 18 yielded no crops whatsoever, though on plot 18 the same amount of this element of food was supplied as was given in the form of carbonate of potash to plot 7, which matured a small but measurable crop (*vide* Plate III (*a*) & (*b*)).

It has been pointed out by Hilgard and others that an amount of phosphoric acid which, in the presence of a deficiency of lime, may prove insufficient for the crops' needs in respect of this element of plant-food, may suffice when lime is present in larger quantities.

lots 20 & 20a. Common manuring - Superphosphate
Nitrate of Soda
Sulphate of Potash.

Plots 21 & 21a. Common manuring - Superphosphat
Sulphate of Ammonia
Sulphate of Potash

lots 22 & 22a. Common manuring - Superphosphate
Nitrate of Soda

Plots 23 & 23a. Common manuring - Superphosphat
Sulphate of Ammoni

lots 8 & 8a. Common manuring - Raw mineral phosphate.

Plots 9 & 9a. Common manuring - Basic Slag.

Undoubtedly added lime would appear to influence the availability of the soil's phosphoric acid content as measured by solubility in 1% citric acid solution, as is shown by the following figures obtained recently from field plots variously limed.

	Per cent. P_2O_5 soluble in 1% citric acid by the method of Dyer.
Unmanured plot	·0018%
Bone meal	·0055%
Lime plot 30 mds. per acre .. .	·0069%
Lime 30 mds. & bone-meal plot	·0087%

This aspect of the action of lime is further borne out by some experimental crop results in the field using insoluble forms of phosphate with and without lime.

Bearing in mind then the beneficial action observed throughout this experiment to follow the use of phosphoric acid in any form, it is quite conceivable that the action of lime may in part be due to some increase in the availability of the existing phosphoric acid supplies of the soil.

As will presently appear, it seems highly probable that the favourable action of phosphoric acid is not to be entirely explained on the ground that it acts merely as a plant-food; by its action on the physiological processes of the root system generally it may assist indirectly in reducing the amount of toxic material in the soil.

The arguments advanced by O. Loew in regard to the physiological significance of establishing certain ratios of lime to magnesia, are clearly incapable of explaining the early observed effect of lime on this soil, since the alkaline carbonates produce a measurable result in the same direction, and, moreover, the effect on crop production is the same, whether the ratio of magnesia to lime is widened by using magnesia or narrowed by using lime, *so long as both are applied in a basic form* (Plate II).

H. B. Hutchinson[1] has pointed out that caustic lime may bring about a measure of partial soil sterilisation, his conclusions being based on tests in which, in the main, heavy dressings of lime were used up to 6·6 tons per acre.

If it be contended that any large part of the beneficial effect of lime on the Jorhat soil is due to partial sterilisation, it is necessary to assume that the other basic dressings used in our experiments also acted in the same way, and at present there does not seem to be any evidence that a dressing of potassium carbonate of 164 lbs. per acre (plot 7) would effect any appreciable amount of partial sterilisation.

From the purely biological point of view, in view of all the evidence which is to be found in literature that acidity definitely retards the work of nitrifying and other soil bacteria, promoting rather the development of moulds, leading to a decline in fertility; and though no special study has been made in connection with this experiment of possible changes in bacterial activity, it is impossible to resist the conclusion that the normal functioning of soil bacteria generally on these soils only becomes possible as a result of early chemical changes following the direct use of a base such as lime.

Nitrification, though greatly reduced, still goes on slowly in acid soils, but is increased by liming, as shown by Hall.[2]

That it is so increased by liming has all along seemed evident in the improved colour of cropping in our various experiments.

The increase in nitrate production, in addition to adding to the food-supply of the plant, would as shown by Schreiner and Reed,[3] further assist the lime in promoting root oxidation, which is followed by a reduction of toxicity due to certain organic toxic soil compounds.[4]

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[1] *Journal of Agricultural Science*, Vol. V, Part 3.

[2] *Nitrification in Acid Soils.* Hall Miller Gimmingham, *Proc. Roy. Soc.*, Vol. 80.

[3] *Bot. Gaz.*, 47, 355.

[4] Schreiner and Skinner. *Ibid*, 50, 161.

That the direct addition of nitrates to the soil on plots 14, 15 and 16 did not result in keeping the crop alive in those cases in the absence of lime, does not disprove this observation in regard to the destruction of toxins incident on improved root oxidation, since the showers which fell after sowing may have largely removed the nitrate beyond the reach of the young roots, and the seedlings were already dead before the second application of nitrate could be made.

Again, even though it had exercised its full effect, it is conceivable that added nitrate may not, in the absence of other contributing agencies, have sufficed of itself to diminish the toxicity sufficiently to enable the crop to survive.

In support of this contention the increase in crop production due to superphosphate without lime, when re-inforced by nitrate of soda, may be cited, this result being reversed when sulphate of ammonia was used, *c.f.*, Plate III (*c*) with Plate IV (*c*) & (*d*).

It is necessary at this stage to consider the rôle which phosphatic manures in the absence of lime have played in the experiment. It was previously pointed out that, of the non-limed series, among the few plots on which the seedlings survived and which matured any crop at all, were four in which superphosphate formed the only common manurial factor.

Phosphoric acid was applied alone in basic form to plots 8 and 9, and as acid superphosphate alone to plot 10, this being reinforced by other manures on plots 20, 21, 22, 23 and 26.

The results show that plots 8 and 9 (Plate IV (*e*) & (*f*)) receiving raw phosphate and basic slag respectively gave the biggest crop of the whole phosphate series, only approached, but not equalled, by superphosphate when used along with nitrate of soda and sulphate of potash on plot 20.

Neither the raw phosphate nor the basic slag supplied sufficient lime to neutralise any but a small part of the acidity of the first three inches of soil, which remained quite acid in reaction. Their favourable action on crop production is, therefore, no doubt jointly

due to their basic character and to the fact that they supply available phosphoric acid. It is, however, quite impossible to divorce these two aspects in the case of these two manures, and thus a consideration of the superphosphate series becomes necessary.

In the absence of lime, superphosphate alone (plot 10) matured a very small short crop; this was increased by the addition of sulphate of potash (plot 26) or nitrate of soda (plot 22), the latter giving the bigger increase, while the largest crop of the series resulted from plot 20 which had both nitrate and potash in addition to superphosphate (Plates III (*c*) & (*d*), and IV (*a*) & (*c*)).

In those cases, plots 21 and 23, in which nitrogen was supplied as sulphate of ammonia, the result so far as the oats crop was concerned, was the absolute negation of the beneficial effect of the superphosphate.

It will be seen then, that the use of acid superphosphate has a small qualitative effect on crop production similar to that exercised by lime, and the other basic manures used.

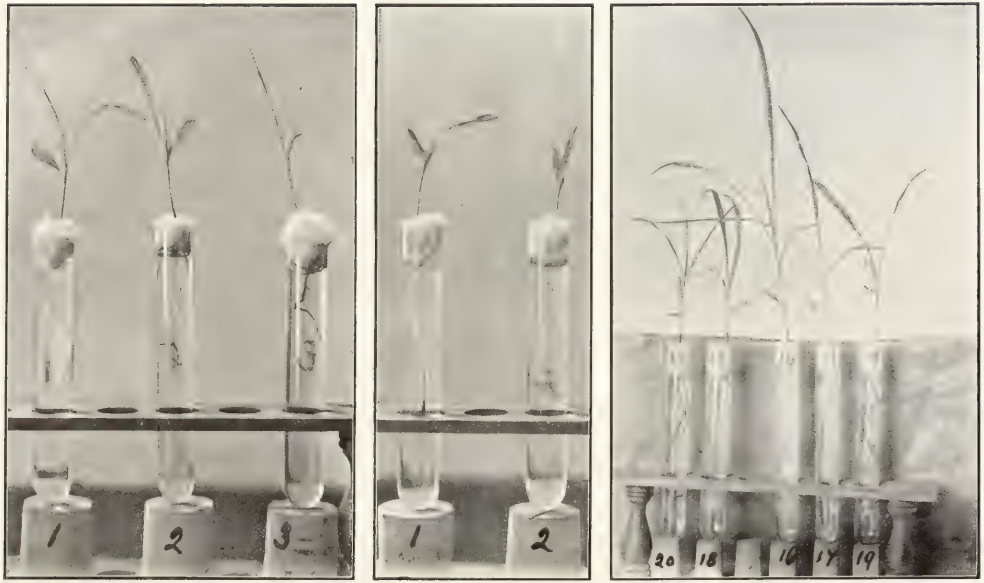
To what are we to ascribe this action? It were unnecessary to point out that it cannot neutralise acidity; at best it can but add a certain amount of sulphate of lime which, as we have seen, has absolutely no effect.

It adds to the soil a certain amount of freely available phosphoric acid, but it does so whether used alone or with nitrate of soda or with sulphate of ammonia. There is no reason to suppose that sulphate of ammonia could in any way affect its action as a source of available phosphoric acid to the plant.

The net effect of using sulphate of ammonia in addition is, however, detrimental by virtue of the increase in soil acidity which follows its use.

In view of the deficiency of phosphoric acid in the soil, it must be granted that superphosphate would function partly as a direct plant-food, providing the general soil conditions are such as to permit the plant to survive.

PLATE V.



(a1) (b1) (c1)

JOWAR SEEDLINGS.

But this function is probably not its only one; by its power to stimulate the root system in the early stages of growth as pointed out by Russell[1] whereby among other things the extra-cellular root oxidation would probably be increased, leading to destruction of toxic material, the survival of the plant might be rendered possible.

Schreiner and Reed[2] show that the roots of plants do exhibit an extra-cellular oxidising power in nutrient solutions, and that phosphates usually produced material increases in the oxidation in solutions to which they were added: further, their experiments showed that "plant roots are able to oxidise a certain amount of deleterious organic material, and that the presence of salts which favour oxidation increase the ameliorating action of the plant."

Experments on *jowar* seedlings in culture solutions of the toxin[3] extracted from the Jorhat soil, also showed that the addition of phosphate materially reduced the toxic effect on the plant.

It may be stated here that the most marked effect of this toxin was on the young roots: their growth was at once stopped, the root became discoloured, generally hooked round and sometimes swelled up at the end, leading to the death of the plant within a short period. These effects were considerably modified by the addition of phosphate, especially where the toxin concentration was low: discolouration was nearly absent and lateral roots were formed. Moreover, it is interesting to note that where 5 c.c. of a complete nutrient solution was added to the toxin solution, the effect of the latter, though still apparent, was still further diminished, again, especially so where the toxin was present in least concentration. (Plate V.)

This comparative behaviour of *jowar* in the presence of the soil toxin in tube cultures, using on the one hand a complete nutrient solution and on the other one containing only phosphate, again

[1] Russell "*Soil Condition and Plant Growth*," pages 36 and 37.

[2] *Bull. 56, Bur. of Soils, U. S. Dept. of Agric.*

[3] The record of the work on this toxin will be published separately—A. A. M.

accorded well with the growth of oats in the field, *vide* plots 10 and 20, in the absence of lime. (Plates III (*c*) and IV (*a*)).

It is obvious that while superphosphate cannot bring about any effects by neutralisation of acidity in the way that lime can, in view of the evidence adduced above, its action may probably be in part due to a destruction of organic compounds which are specifically toxic, whose presence or accumulation is probably only possible in sour soils deficient in basic ingredients, but whose destruction may be brought about by such treatment of, or addition to, the soil as stimulates oxidation, whether by the roots or other biological agencies.

Part, if not the whole, of the noxious matter of our soil is acid, but on many grounds it is unreasonable to suppose for a moment that the entire acidity of the soil or, indeed, any but a very small part of it, is made up of acids which are specifically toxic, in the way that the hydroxystearic acids are, for instance.

No method of determining what part of the acidity may be due to acids specifically toxic has yet been devised, as the methods of isolation employed are not quantitative, so it is impossible to say in any given case what part of the acidity is due to specifically toxic acids and what is not. But, on the reasonable assumption that the total acidity is the sum of two factors, one specifically toxic and the other not, then the superior action of lime on crop production may be explained on the ground that, directly or indirectly, it leads to the destruction of both factors, thus establishing better soil conditions than may follow a temporary diminution in the amount of specifically toxic material alone, which may be brought about by superphosphate, but which is sufficient to permit of some growth even in the presence of the remaining acidity.

That the sum total of soil acidity is commonly not due to specifically toxic acids is further borne out by a statement by Storer[1] to the effect that fairly good crops of oats, amongst

[1] *Agriculture*, Vol. II.

other crops, are grown on many German moors which exhibit a strong acid reaction, both as regards surface and sub-soils.

However, the presence, in excess of a certain amount of acids which are not specifically toxic in themselves, may prevent crop production as is proved by a comparison of plots 10 and 23 (Plates (*c*) and IV (*d*)). The addition of sulphate of ammonia on the latter plot, to the superphosphate used in both, though supplying nitrogen, increases the general acidity by leaving a residue of sulphuric acid, which may inhibit to some extent the increased root oxidation which would follow on the use of superphosphate alone, since Schreiner and Reed observed that the activity of the peroxidase produced by roots is somewhat inhibited by the presence of acid, being greatest in neutral or slightly alkaline solutions: and again, of course, normal bacterial acidity is reduced with increase in soil acidity.

That the beneficial action of the superphosphate was entirely inhibited, however, by addition of sulphate of ammonia seems to be unlikely in view of some observations made on the growth of weeds on these plots in general.

More or less weed growth (chiefly grass) was apparent on all the non-limed plots, with the exception of plot 11, which had sulphate of ammonia alone; this plot was absolutely bare even of weeds.

Plots 21 and 23 (superphosphate and sulphate of ammonia) were covered with a luxuriant growth of weeds, but no oats. (Plate I (*b*)).

It will be seen then that sulphate of ammonia used alone had such an effect in general as to render the soil incapable even of weed production in the cold weather. The power, however, to grow weeds was restored and the weeds grew more luxuriantly than ever, when superphosphate was used in addition.

Though this increased vigour of weed growth may be due to the phosphoric acid acting as direct plant-food, the restoration

of the power to produce weeds at all can, it would seem, have no connection with direct food action, as the ability to grow weeds is equally ensured by withholding the ammonia sulphate in the first instance, in the absence of any direct addition of phosphoric acid.

The restoration of this capacity to produce weeds effected by superphosphate after the use of sulphate of ammonia, may then be due to its power to bring about some diminution in toxic content, which, though not sufficient to yield any oats, is quite enough for the purposes of weed growth.

It is not unreasonable to suppose that improved processes of oxidation, whether by the roots themselves or following on increased bacterial activity, will result in the partial or complete destruction of toxic compounds.

Some of these compounds, already isolated and identified by Schreiner and his associates, have proved to be easily oxidisable compounds, which a study of their chemical constitution would premise.

Further, the toxin solutions used in the author's experiments with *jowar* seedlings, after mere exposure in a flask to light and air for several weeks, were very largely deprived of their toxicity thereby.

A consideration of the following facts :—

(1) that the mere use of lime renders crop production possible, being especially effective when used in sufficient quantity to render the surface soil neutral or faintly alkaline ;

(2) that superphosphate has a similar qualitative effect, apparently much smaller than that of lime, but becoming greater when reinforced by nitrate of soda ;

(3) that toxic organic compounds capable of being destroyed by oxidation are present in the soil ;

(4) that lime, nitrates, phosphates are all able to promote biological oxidation, whether by the plant roots themselves or by other biological agencies,

would lead to the conclusion that the ability of this soil to produce certain crops is dependent on the diminution of toxic agencies present: that the more complete the destruction the bigger the crops will be, but that the best results only follow on an entire elimination of acidity, whether due to specifically toxic compounds or not: the latter observation would explain the very much more marked action of lime, as opposed to that exercised by superphosphate, which is clearly proved by the fact that though the use of sulphate of ammonia is able to completely negative the effect of superphosphate so far as the production of oats is concerned, its addition with previous liming is followed by no such consequence, though, even in this case, one would hesitate to say that its use has proved beneficial, *c.f.*, sub-plots 4*a* and 19*a* with 11*a*; 18*a* with 25*a*; 26*a* with 21*a*: also 10*a* with 23*a*. Only in the last case, *i.e.*, where sulphate of ammonia is added to superphosphate, in the presence of lime, is an increase registered from its use. On the contrary, it is interesting to note here that similar comparisons amongst the nitrate of soda-limed plots come out in favour of the nitrate in every case but one.

It would appear that toxic compounds have not been found to be definitely associated with any soils but such as are sour, often badly aerated, and deficient in calcium carbonate. It does not follow therefrom that all sour soils harbour specific toxins.

While any degree of acidity is more or less harmful on biological grounds to many cultivated plants, the case becomes greatly aggravated when such acidity is partly due, as in the Jorhat soil, to specifically toxic organic compounds. These compounds owe their continued presence in dangerous amounts in the soil to the impairment of oxidation processes which follow on the establishment of acid conditions in soils deficient in basic ingredients. A reduction in the amount of the toxic compounds merely, such as

may follow the use of superphosphate and other fertilizers, can only be a temporary measure and does not cut at the root of the evil. The general conditions which originally gave rise to toxin formation still remain. Something more is necessary, and these experiments show, I think, that for the best results, the addition of a basic substance such as lime is clearly necessary, while other experiments being made point to the fact that sufficient base must be used to completely neutralise the soil, at any rate to cultivation depth, and periodical additions will be necessary to prevent a relapse into sourness. Infertility in a soil is not, in many cases, a mere negative property, but is often due to the presence of an overwhelming positively injurious factor. Alter or remove this factor, and all the elements of fertility will frequently be found to be present. Greig Smith[1] records the case of a soil which was very toxic, becoming normal after heavy rains due to washing down of the toxin into the lower layers.

The work on partial soil sterilisation at Rothamsted, also that of Schreiner and his associates on soil organic matter, show that it is undoubtedly true that the soil, both in regard to its hosts of living organisms as well as the chemical compounds present, may harbour mutually opposing factors, and that soil fertility varies as the balance between them changes or is deliberately altered.

This balance may be varied by cultivation, manuring, the use of lime, cropping and the rotation of crops, as well as by partial sterilisation by heat or antiseptics.

The harmful factor is certainly in the ascendancy in the Jorhat soil, and lime clearly seems to be the most effective agent in bringing about a change for the better.

Schreiner and Lathrop[2] referring to toxic soils of low oxidising power observe that "liming, drainage, and the application of good organic manures are the most potent factors in promoting oxidation in soils. Liming has been found to be very beneficial,

[1] *Centr. Bakt.*, June 22, 1912.
[2] *Bull.* 80. *Bur. of Soils, U. S. Dept. of Agriculture.*

aiding the destruction of harmful bodies of this nature, both by combining with them and also by oxidising them to other less harmful or even beneficial compounds. Drainage also aids materially in two ways ; first, it allows a freer access of air with deeper penetration of healthy roots, which in time promotes oxidation and thus aids the destruction of organic matter ; secondly, it produces beneficial results by an actual removal of the harmful material in the drainage waters, as well as perhaps eliminating the cause of its formation. The addition of good organic manures will also assist in the destruction of the compounds already in the soil. The introduction of easily decomposed organic matter causes greater bacterial activity and greater oxidation in the soil, so that through the inauguration of the processes of its own decomposition, it has the effect of causing the changes in the organic matter in the soil to proceed in a different direction from that which formerly existed. The fertilizer salts are shown by experiments to act in a very similar manner, inducing or quickening changes which take place without them only very slowly or not at all." Our general experience at Jorhat bears the above out very strongly, and our experiments show that either as regards intensity or permanence of effect, lime is clearly unapproached by any ordinary combination of manures.

Its functions are such as are obviously shared by other basic substances, and whatever other changes may follow later, there can be no doubt that its effect depends primarily upon its power to neutralise acidity and to destroy toxic material. At the same time, the use of caustic lime may lead to a diminution of protozoal content and activity ; in the result, oxidation processes are improved, a great impetus is given to the activities of soil bacteria, the improved bio-chemical factor leads to the production of compounds beneficial to plant life, and fertility results.

Since the foregoing was written, the 2nd year's crop of oats has been sown and is now in ear ; the results confirm very closely those of the first year, and at present suggest no modification whatever of the conclusions which have been drawn therefrom.

One point worthy of special mention is that one of the unlimed and otherwise untreated plots was watered daily from the time of germination. This had not the slightest effect on the survival of the crop, which died out as usual in the seedling stage.

This disposes finally of any contention that the crop fails to survive for want of moisture, and also that the action of lime is in any way connected with any effect it might have on the supply of water to the plant by the soil.

Other points which might also be briefly mentioned are as follows :—

1. Plot 1 (ground limestone) is a great improvement on last year.
2. Plots 2, 3 (sodium carbonate) are again cropping, with No. 2 better than No. 3 in the second year.
3. Plots 6 and 7 (potassium carbonate) are almost bare ; the effect of small initial dressings of soluble alkali carbonates is evidently very transitory.
4. Plot 5 (magnesia carbonate) is equal to last year.
5. A new plot, to which an excessive quantity of superphosphate was applied (160 lbs. sol. P_2O_5 per acre), points to the conclusion that the use of excessive amounts of acid superphosphate, in the absence of lime, is detrimental, presumably by virtue of the extra acidity added to the soil.

EXPLANATION OF PLATES.

Frontispiece.

Jorhat Farm. Block G.

The plots on the left were limed, those on the right unlimed; treatment is otherwise identical. Oats and gram were sown across both areas. Observe the standing crops of both on the limed side, and the absolute failure on the other.

Plate I.

(*a*) General view of plots described in this paper. Compare the crop on the limed ends of the plots (right side of picture), with that on the unlimed ends (left side).

(*b*) Showing the action of phosphate on weed production. The plots in the foreground to the left received superphosphate; that on the right was unmanured.

Plate II.

(*a*) Plots 1 and 1*a*. Common manuring = ground limestone.

(*b*) Plots 19 and 19*a*. Common manuring = *nil*.

(*c*) Plots 3 and 3*a*. Common manuring = sodium carbonate, light dressing.

(*d*) Plots 5 and 5*a*. Common manuring = magnesium carbonate.

Plate III.

(*a*) Plots 7 and 7*a*. Common manuring = potassium carbonate, light dressing.

(*b*) Plots 18 and 18*a*. Common manuring = sulphate of potash. supplying the same quantity of potash as applied in basic form to plots 7 and 7*a*.

(*c*) Plots 10 and 10*a*. Common manuring = superphosphate.

(*d*) Plots 26 and 26*a*. Common manuring = superphosphate, sulphate of potash.

PLATE IV.

(*a*) Plots 20 and 20*a*. Common manuring = superphosphate, nitrate of soda, sulphate of potash.

(*b*) Plots 21 and 21*a*. Common manuring = superphosphate, sulphate of ammonia, sulphate of potash.

(*c*) Plots 22 and 22*a*. Common manuring = superphosphate, nitrate of soda.

(*d*) Plots 23 and 23*a*. Common manuring = superphosphate, sulphate of ammonia.

(*e*) Plots 8 and 8*a*. Common manuring = raw mineral phosphate.

(*f*) Plots 9 and 9*a*. Common manuring = basic slag.

PLATE V.

(*a*) *Jowar* seedlings

Tube 1 = water.

,, 2 = Toxin solution (125 pts. per million) + lime-water to neutrality.

,, 3 = Toxin solution (125 pts. per million).

Root development in tube 2, though not so good as that in water, was much greater than that in tube 3, to which no lime-water was added.

In many other similar cultures, the effect of lime in promoting root development in the presence of the toxin was always well marked.

(*b*) *Jowar* seedlings.

Tube 1 = water.

,, 2 = Toxin solution, concentration 80 parts per million.

The very marked repressive action of the toxin in tube 2 on root development was produced within 48 hours.

A solution of only 40 parts per million was equally effective.

(*c*) *Jowar* seedlings.

Tube 16 = 5 c.c. nutrient solution + water.

,, 17 = 5 c.c. nutrient solution + toxin solution, concentration 100 per million.
,, 19 =

,, 18 = 5 c.c. nutrient solution + toxin solution, concentration 240 per million.
,, 20 =

Nutrient solution:

KNO_3	0·5 grm.
$MgSO_4$	0·5 grm.
$CaSO_4$	0·5 grm.
Na_2HPO_4	0·5 grm.
Fe_2Cl_6	2 drops.

APPENDIX.

A. Chemical Analysis of the Jorhat surface and sub-soils.

		Surface-soil.	Sub-soil.
		%	%
[illegible]	Phosphoric acid (P_2O_5)	0·025	0·020
	Potash (K_2O)	0·115	0·135
	Lime (CaO)	0·154	0·144
	Magnesia (MgO)	0·166	0·148
[illegible]	Phosphoric acid	0·008	0·008
	Potash	0·067	0·041
[illegible]		3·26	1·84
[illegible]		0·113	0·051
[illegible]		0·093	0·097
[illegible]		0·052	0·015
[illegible]		5·03	Acid

B. Mechanical Analysis (ignited fractions).

		Surface-soil.	Sub-soil.
		%	%
[illegible]	(1·0—2·0 m.m. diam.)	*Nil.*	*Nil.*
[illegible]	(0·2—1·0 m.m. diam.)	7·2	6·4
Fine ,,	(0·2—0·04 m.m. diam.) ..	42·5	42·8
[illegible]	(0·04—0·01 m.m. diam.)	32·6	17·6
[illegible]	(0·01—0·002 m.m. diam.)	9·0	9·4
Clay	(< 0·002 m.m. diam.) ..	6·6	9·9
[illegible]	[illegible]	2·1	3·1
		99·0	99·1

C. *Moisture Constants.*

	Hygroscopic Capacity.	Maximum water-saturation capacity.		Minimum water-saturation capacity.		Moisture in air-dry soil.
		Per cent. of water in saturated soil by weight.	Per cent. of water in saturated soil by volume.	Per cent. of water by weight.	Per cent. of water by volume.	
Surface soil	3·10	31·9	50·5	11·2	13·9	1·3
Sub-soil	..	30·0	50·0	7·2	9·1	1·19

D. *Acidity.*

Expressed as parts quicklime (CaO) required to neutralise one million parts of air-dry soil, the acidity of the surface and sub-soils on the Jorhat Farm varies between the following limits :—

Surface soil 880—1350 parts CaO per million.

Sub-soil 650—770 parts CaO per million.

JORHAT,
September, 1913.

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